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VARIATION OF BIOMEDICAL PARAMSETERS IN LIVER POST TRANSPLANT PATIENTS: FOLLOW-UPS FOR SEVEN MONTHS.

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ABSTRACT

Background: *While organ transplants are considered highly effective life-saving therapeutic approaches, they also create markedly complex physiological changes within the body that require careful monitoring to achieve optimal health outcomes.*

Objectives: *This research is a longitudinal study spread over 7 months of follow up of post transplantation of liver. The assessment has been carried out through changes in biochemical parameters i.e. albumin, liver enzymes etcetera.*

Methodology: *Patients were selected from the hospital of Gombat Institute of Medical science, Disrict Khairpur, Sindh, Paksistan. Study was approved by the Ethical committee of Institute of Biochemistry (Reference IOB/306e/dated 01-02-2023), University of Sindh. Research was carried out from februay 2023 to February 2025. Patient's age was from 20 to 50 years. All patients were liver transplanted. Informed consent was signed by all patients. Basic data and blood samples for biochemical parameters were collected from patients. Purposive sample technique was used. Liver function test (LFT), serum Albumin All biochemical assessment was done at laboratory through standard scientific methods.*

Results: *Rigorous evaluation of ALT distributions across all monitoring intervals demonstrated pervasive departure from normality. Month1 exhibits severe right-skewed distribution with extremely high outliers (W-statistic=0.3595,p-value=0.0000) , as evidenced by the heavily skewed histogram and marked Q-Q plot deviation. This pattern of severe non-normality persists throughout the entire follow-up period, month 2 (W-statistic=0.4364, p-value=0.0000), month3(W-statistic=0.5701, p-value=0.0000), month 4 (W-statistic=0.5560, p-value=0.0000), month 5 (W-statistic=0.5787, p-value=0.0000), month 6 (W-statistic=0.6581, p-value=0.0000), and month 7 (W-statistic=0.5705, p-value=0.0000).*

Conclusion: *It is evident from these findings that the use of systematic, protocol-based monitoring by means of parameters specific to the time-period of the post-transplant ESRD course are critical for the early recognition of graft dysfunction, graft rejection, infectious processes and metabolic abnormalities. With a thorough knowledge of the patient's typical recovery trajectory and distribution pattern, clinical monitoring should occur on an individualized basis. Through this process, personalized vigilance is required to provide prompt detection of graft dysfunction, graft rejection, infection and metabolic) complications. Ultimately, this will improve both graft survival and long-term patient outcomes.*

Keywords: *Organ Transplantation, Post-Operative Monitoring, Hematological Parameters, Liver Function Tests, Statistical Normality, Friedman Test, Immuno suppression, Graft Rejection.*

INTRODUCTION

The liver is the largest and most important metabolic organ, playing a pivotal role in integrating several biochemical pathways of carbohydrate, fat, protein, and vitamin metabolism. The liver has a metabolic function, and when affected by disease may lead to nutritional deficiency status, with liver disease patients usually suffering from Protein-Energy Malnutrition (PEM). Its appearance is caused by different factors, which include inadequate food intake, abnormal nutrient metabolism and altered digestion and absorption, together with an increased catabolism and an increase in protein-energy requirements [1-3]. Main responsibility of liver is metabolism, due to any cause when it does not work. Now most successful treatment for liver damage is liver transplant. Liver transplantation is medical procedure, an healthy donor donate a healthy piece of liver for patient; liver implant by surgical procedure [4-5]. After successful procedure, patient has been observed or follows for healthy life or another words focused on the function as s synthesis of protein and other biochemical compounds. Mostly patients were monitor through Liver function test (LFT), complete blood count (CBC), Urea and International normalized ratio (INR). Liver function is monitor through liver function test; in the liver function test each parameter have importance for the assessment of normal function of liver. Alkaline phosphatase (ALK PHOS) is an extremely important marker of hepato-biliary function. High levels of ALK PHOS suggest cholestasis, obstruction of the biliary ducts, or graft dysfunction. Aspartate aminotransferase (AST) is a sensitive indicator of hepatocellular damage with a wider distribution than ALT, including the liver, skeletal muscle, cardiac muscle, and erythrocytes. In the post-transplant scenario, AST indicates hepatocellular damage that can also originate from other sites. AST and ALT ratios are more informative as values can indicate other sources of damage or more pronounced Hepatic Fibrosis, though a sudden drop suggests Graft Recovery [6-9]. Total bilirubin is a sensitive marker of excretory function of the liver. Persistent hyperbilirubinemia, especially if present after the acute phase following transplantation, requires immediate evaluation [10]. Ongoing and regular assessment of these biomedical indicator for early deduction of liver abnormalitie. Systematic laboratory monitoring has therefore become an essential component of contemporary transplant practice [4,11]. Albumin is important protein of human being, it is especially synthesis by liver cells (hepatocytes). Its works as vehicle in blood, it circulate in blood and carry or compounds such vitamins, fatty acids, drugs, hormones and other components. Low level of albumin known as hypoalbunism, this may cause due to of malnutrition or indication of liver dysfunction. Hypoalbuminemia in the early post-transplant period is associated with surgical stress and capillary leak syndrome [10,12]. In this piece of research; liver transplanted patients were selected and monitored (follow up) for liver function through biochemical parameters for seven months.

Methodology:

Patients were selected from the hospital of Gombat Institute of Medical science, Disrict Khairpur, Sindh, Paksistan. Study was approved by the Ethical committee of Institute of Biochemistry (Reference IOB/306e/dated 01-02-2023), University of Sindh. Research was carried out from februay 2023 to February 2025. Patient's age was from 20 to 50 years. All patients were liver transplanted. Informed consent was signed by all patients. Basic data and blood samples for biochemical parameters such as Liver function test (LFT) [13,14], serum Albumin [15] were collected from patients.this was seven months follow-ups research; after every month blood samples were collected from patients for analysis of biochemical parameters. Purposive sample technique was used. All biochemical assessment was done at laboratory through standard scientific methods.

Statistical Distribution Patterns:

Normality testing was a corner stone of the analysis. Parameters related to acute injury and stress (ALT, AST, ALK PHOS, Bilirubin) consistently demonstrated non-Gaussian, right-skewed distributions with significant outliers. In contrast, parameters like early-post-transplant INR and albumin showed periods of normal distribution, influencing the choice between parametric (e.g., RM-ANOVA) and non parametric (e.g. Friedman test) longitudinal comparison methods.

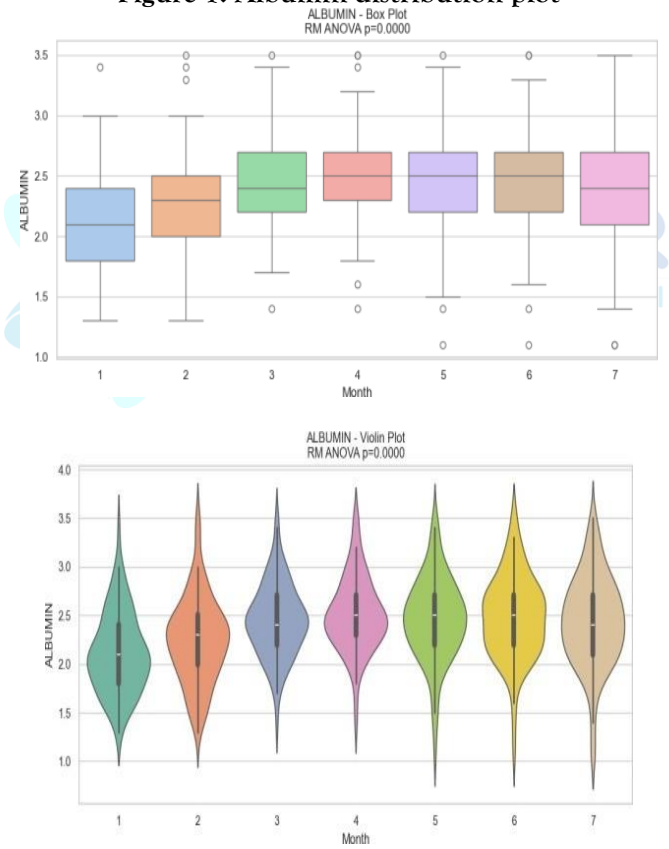
Results:

Serum Albumin:

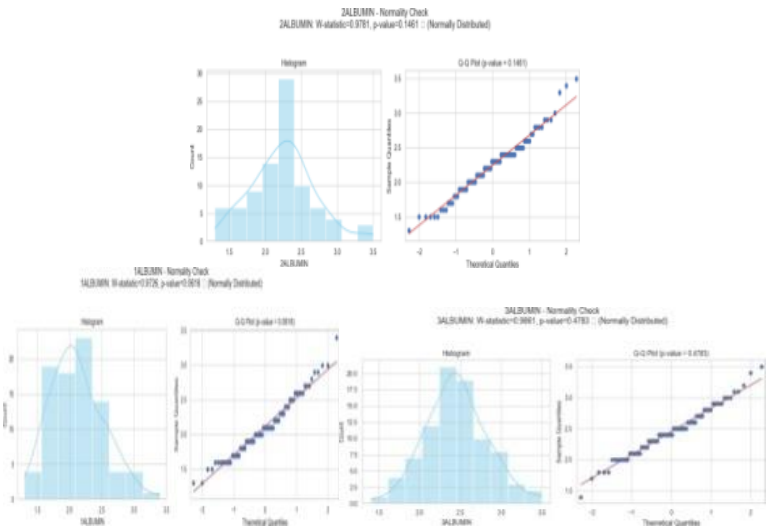
The multiple statistical plots were generated across seven consecutive post-transplant months. The violin box and box plot show albumin concentrations to be of a stable distribution around each time point with the median values being between 2. 0 and 2. 5 g/dL. The strip chart further elucidates that patients' albumin values tend to vary around a median point and, at times, values extend on both ends. Notably, albumin values indeed vary significantly with time, as indicated by repeated measures ANOVA, with a result of p=0.0000. This is expected when taking into account former studies on patients who underwent a transplant recovery [15,16,17].

(a) Voilin plot (b) Box plot

Figure 1: Albumin distribution plot



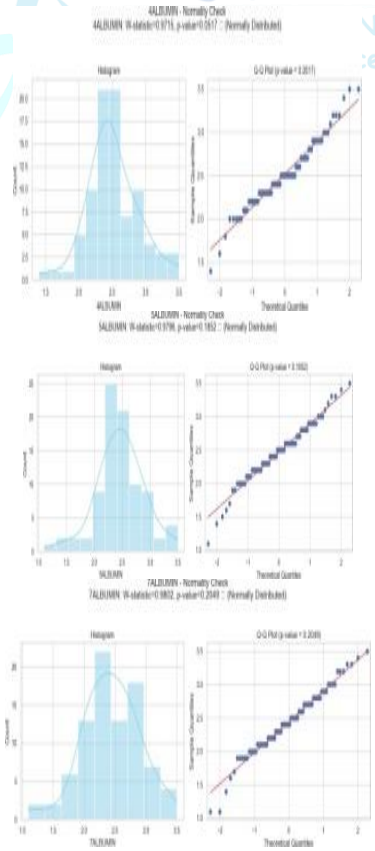
The appropriateness of using either parametric or non-parametric statistical analysis techniques has been explored on the basis of the normality of the distribution of albumin levels (shown in figure no.1) in critical points in time. In month one, the distribution is only marginally normal (W-statistic = 0.9726, p-value = 0.0618), with an almost symmetrical distribution and points lying in line in the Q-Q graph.Similarly, month 2 shows normal distribution (W-statistic = 0.9781, p-value = 0.1461), and month 3 also maintains normality (W-statistic = 0.9861, p-value = 0.4783).

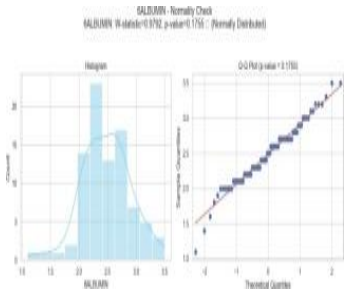


after1month (b) after 2 months (c) after 3months

Figure 2: Normality checks of 3months

However, by month 4, the distribution begins to show borderline non-normality (W-statistic = 0.9715,p-value = 0.0517),with slight deviations visible in the Q-Q plot tails. What this trend shows is that as the data post-transplant tends to be normally distributed in the early stages, there may be a concern in the later stages about normality. The entire normality test for the first seven months (with months 5, 6, and 7 retaining normality with p-values of 0.1852, 0.1755, and 0.2049, respectively) shows that there is still no issue with using parametric analysis for testing albumin (figure no.2).





after 4 months (b) after 5 months (c) after 6 months (d) after 7 months

Figure 3: Normality checks of Serum Allumin after 4, 5, 6 and 7 months

Selective stability of the albumin levels for most months (see figure no.3), in addition to the significance of the RM ANOVA results, supports the notion that it is crucial to regularly assess levels of albumin in post-transplant patients. Sustained hypoalbuminemia beyond the initial post-transplant month could suggest an imbalance in nutrition, especially in inflammation, hepatic dysfunction, or protein-losing disorders necessitating directed therapy.

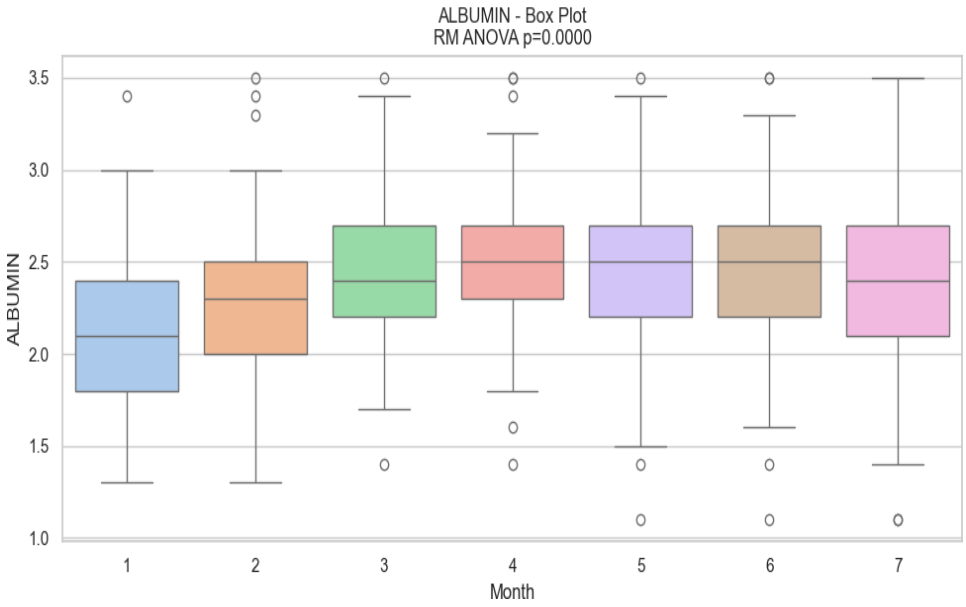


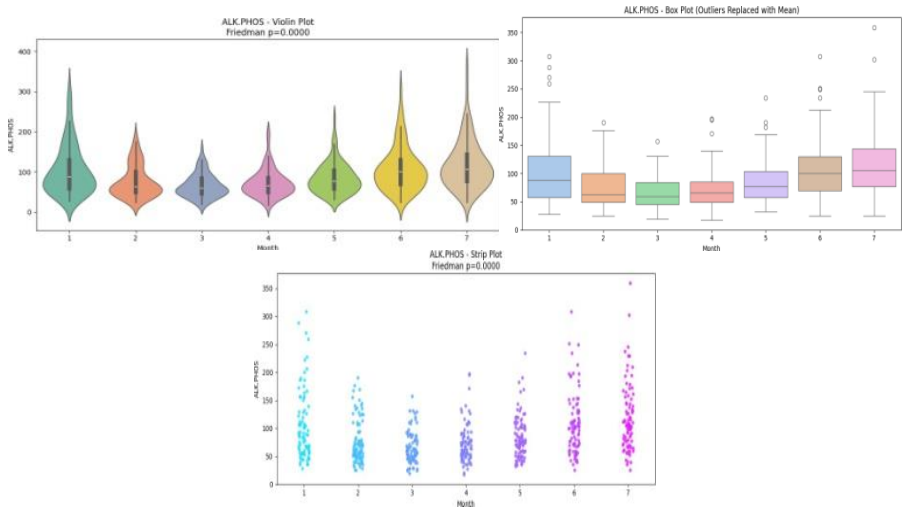
Figure 4: Box plot of Serum Albumin

This box plot illustrates the variation in Albumin values monthly for seven months (shown in figure no.4). The median values increase monthly, with a number of outliers recorded every month. The p, value (0. 0000) is significant, indicating a significant difference in the levels of Albumin recorded monthly.

LiverFunctionTests (ALT,AST, Bilirubin)

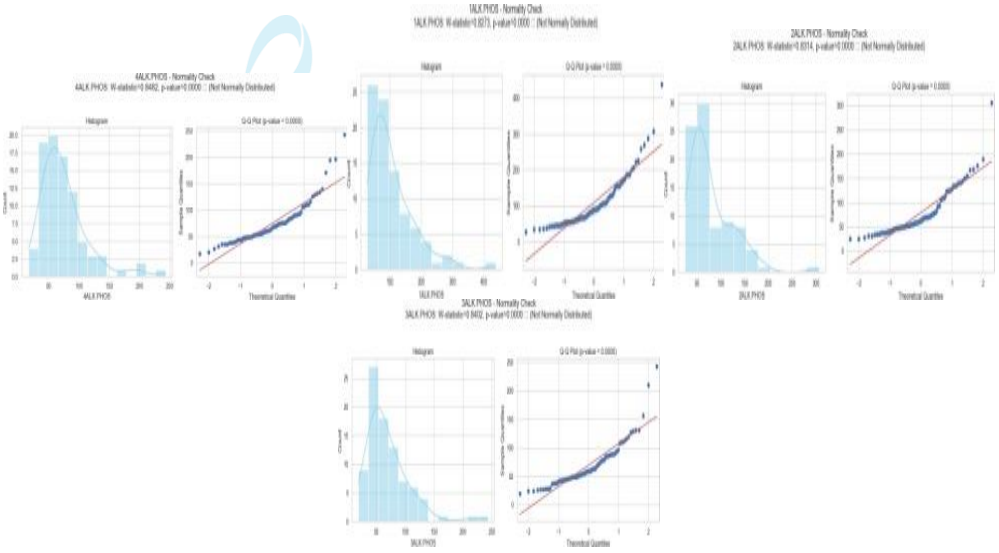
The non-normal distribution of all data points across all times suggests the need for purely non-parametric statistical tests [2] Monitoring ALK PHOS trajectories provides early warning signals for complications such as biliary strictures, acute rejection, or drug-induced cholestasis. Temporal changes in ALK PHOS level sa crosss even post-transplant months were visualized using strip lots, violinplots, and box plots. In the strip plot, there are clear variations between individuals in terms of high variability of ALK PHOS levels ranging between 20 to 350 U/L, with clear outliers in the early months, indicating acute biliary issues. In the violin plot, box plot, it can easily be observed that median levels of ALK

PHOS are gradually decreasing from month 1 (median 90 U/L) through month 4 (median 65 U/L), with a slight increase in months 5 to 7 (median 80-110 U/L). It can be observed that the Friedman test proves significant differences in the levels of ALK PHOS over time (p=0.0000).



(a) Strip plot of ALKPHO (b) Box Plot of ALKPHOS (c) violin plot of ALKPHOS

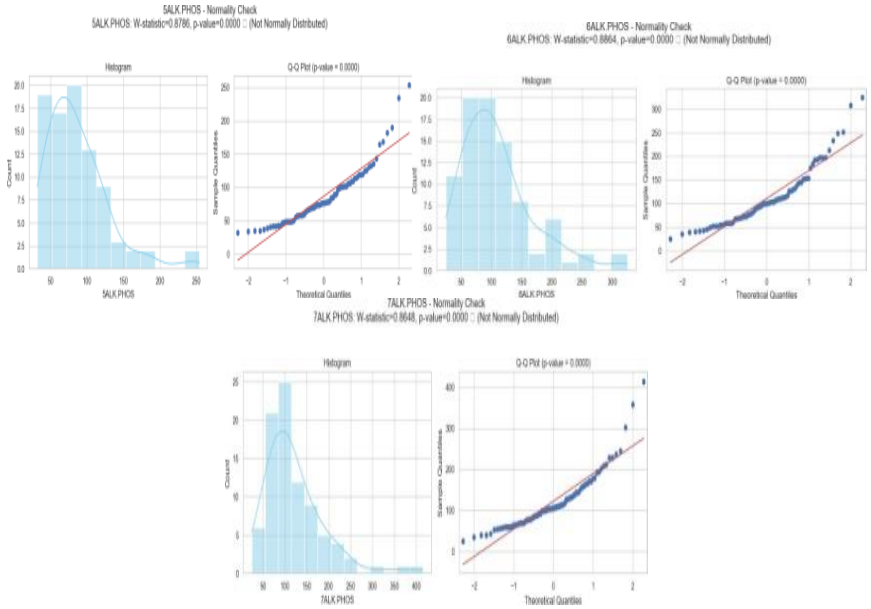
Figure 5: Distribution plots of ALKPHOS



(a) After 1 month (b) After 2 months (c) After 3 months (d)After 4 months

Figure 6: Normality checks after first 4 month

To validate the choice of statistical methods, ALKPHOS distributions (shown in figure no.5) were assessed for normality at eachtime point using Shapiro-Wilktests, histo grams, and Q-Q plots. Month 1 demonstrates marked deviation fromnormality (W-statistic=0.8273, p-value=0.0000), with a pronounced right-skewed histo gram and substantial out liers visiblein the Q-Q plot. This non-normal pattern persists through out the monitoring period, as evidenced by month 2 (W-statistic =0.8314, p-value =0.0000), month 3 (W-statistic = 0.8402, p-value = 0.0000), and month 4 (W-statistic = 0.8482, p-value = 0.0000).



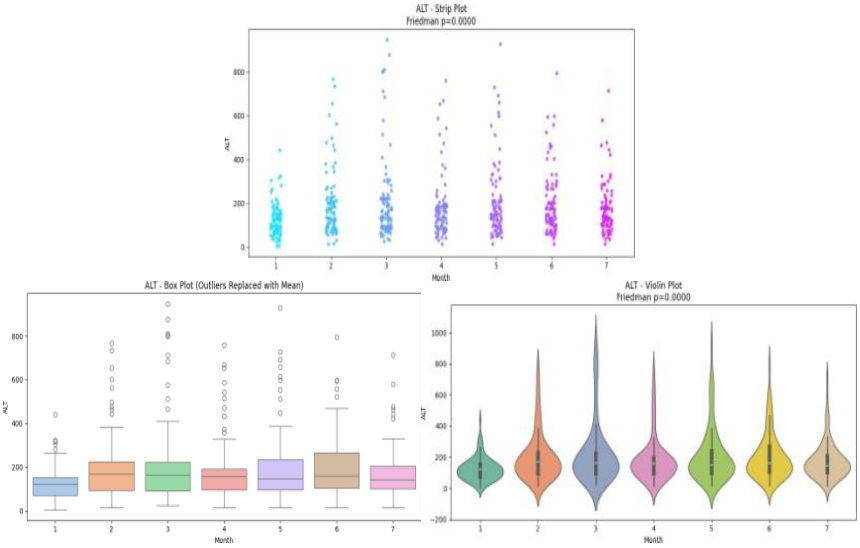
(a) After5months (b) After6months (c) After7months

Figure 7: Normality checks of ALKPHOS after5, 6 and 7 Months

Later time points continue to exhibit non-normality, with month 5 (W-statistic=0.8786,p-value= 0.0000),month6(W-statistic = 0.8864,p-value = 0.0000),andmonth7(W-statistic = 0.8648, p-value=0.0000) all failing normality tests (figure no. 6). The fact that there are right-skewed distributions with high value outliers in all months indicates the need to use non-parametric statistical methods, such as the Friedman Test, to analyze ALK PHOS.

The steady elevation and high level of variability of ALK PHOS shown in figure no.7 in these patients, especially in the first three months, may represent either ongoing biliary adaptation, cholestasis associated with immunosuppressive, or silent rejection. The large values of change documented by repeated measures analysis underscore the need for individualized follow-up of ALK PHOS levels for patients who need biliary studies and/or adjustments of immunosuppressive therapy.

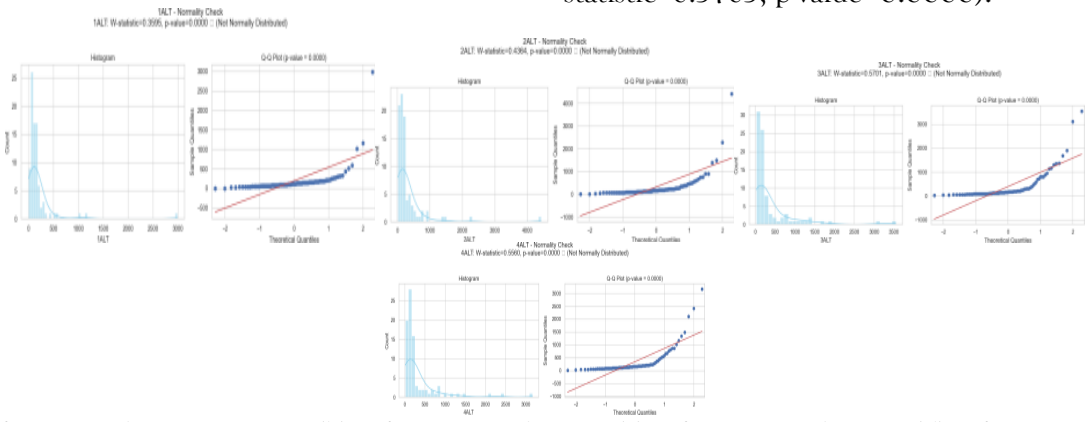
Month 1 has the highest median ALT value (130 U/L); for month 4 the median ALT level has decreased to 125 U/L; and month's 5-7 show relative stability with median ALT levels per month remaining between130-185 U/L (figure no. 8). The Friedman test for significance demonstrated statistically significant changes in ALT levels over time (p=0.0000) which indicate meaningful clinical changes meriting further monitoring.



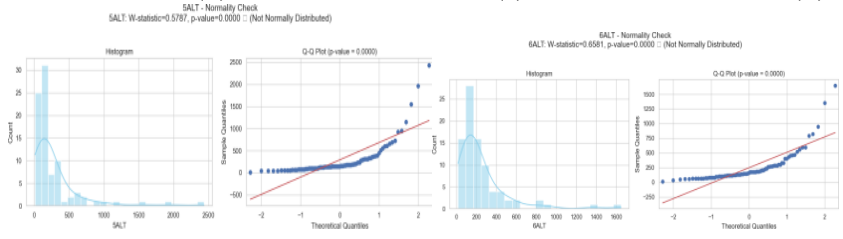
(a)ALT Strip plot (b) ALT Box plot (c) After 7 months

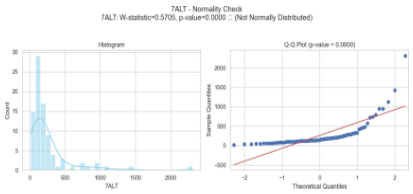
Figure 8: Distribution of ALT

Rigorous evaluation of ALT distributions across all monitoring intervals demonstrated pervasive departure from normality. Month1exhibitss ever right-skewed distribution with extremely high out liers (W-statistic = 0.3595, p-value = 0.0000), as evidence d by the heavily skewed histogram and marked Q-Q plot deviation. This pattern of severe non-normality persists throughout the entire follow-up period: month 2 (W-statistic=0.4364, p-value=0.0000), month 3 (W-statistic=0.5701, p-value=0.0000), month 4 (W-statistic=0.5560, p-value=0.0000), month 5 (W-statistic=0.5787, p-value=0.0000), month 6 (W-statistic=0.6581, p-value=0.0000), and month 7 (W-statistic=0.5705, p-value=0.0000).



(a)After1month (b) After 2 months (c) After 3 months (d) After 4 months





(e) After 5 months (f) After 6 months (g) After 7 months

Figure 9: Normality checks of ALT after 1,2,3,4,5,6 and 7 months

The persistent elevation and high variability of ALT, especially during the first three months following transplantation, underlines the critical importance of frequent ALT monitoring in early graft surveil- lance. Serial measurements of ALT help in distinguishing self-limited ischemia-reperfusion injury from acute rejection or other serious hepatic complication. Rigorous evaluation of ALT distributions across all monitoring intervals demonstrated pervasive departure from normality. Month1exhibits severe right-skewed distribution with extremely high outliers (W-statistic=0.3595,p-value=0.0000) , as evidenced by the heavily skewed histogram and marked Q-Q plot deviation. This pattern of severe non-normality persists throughout the entire follow-up period: month 2 (W-statistic=0.4364,p-value=0.0000),month3(W-statistic=0.5701, p-value=0.0000), month 4 (W-statistic=0.5560, p-value=0.0000), month 5 (W-statistic=0.5787, p-value=0.0000), month 6 (W-statistic=0.6581, p-value=0.0000), and month 7 (W-statistic=0.5705, p-value=0.0000) see figure no.9. Gradual stabilization beyond month 4 may indicate the establishment of immunological tolerance or resolution of acute injury mechanisms; however, the continued presence of outliers in some individual patients needs investigation for occult complications. Detailed normality check plots for all seven months are presented in the Appendix. Highly Right-skewed distribution patterns noticed in the study are typical of post-transplant patterns of injury reported earlier [1]. AST distribution over the first seven months post-transplant reveals considerable variation from individual to individual, though there seems to be a definitive drop over the months. Strip charting indicates the existence of considerable outliers, prominently noticed from months 1 to 3, though values vary from near-zero to about 850 U/L. Both violin and box charts reflect that the maximum values seem to exist during the first month (200 U/L), followed by a plateau with a gentle rise to (200-220 U/L) during months 2-3, and a sharp drop from months 4 to 7 with median values of (140-80 U/L). AST values over the seven months are again confirmed by the Friedman test to be extremely significant (p=0.0000), suggesting the existence of notable long-term trends.

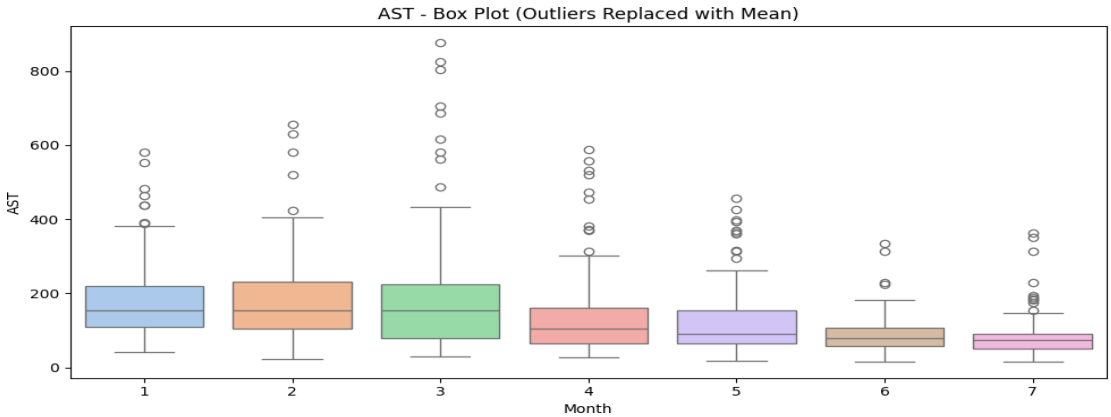
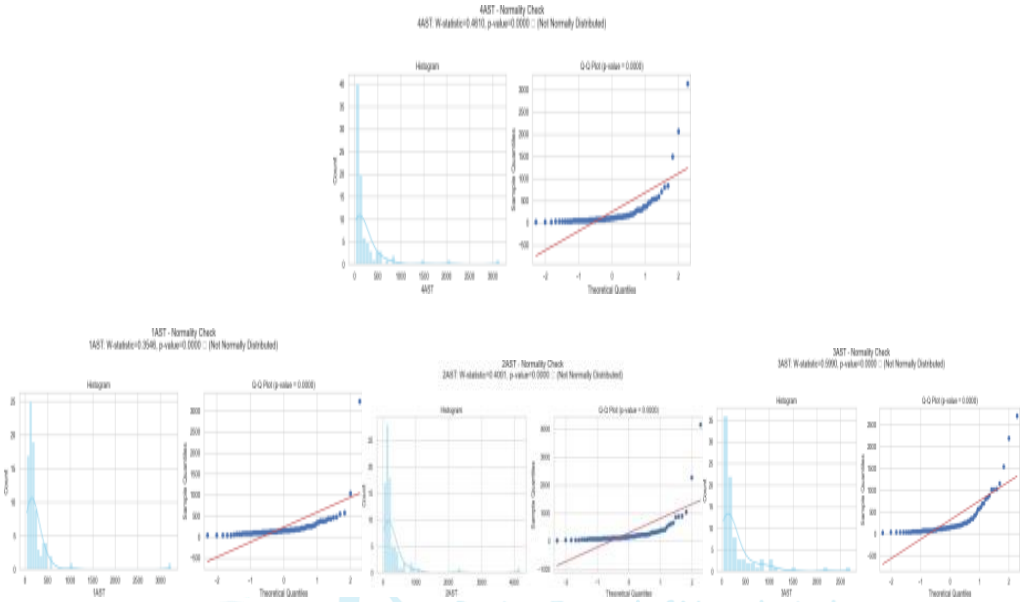
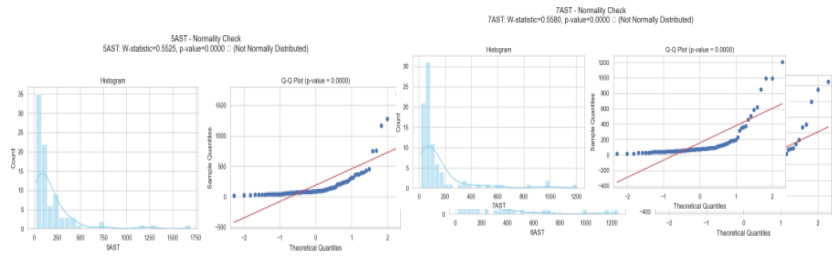


Figure 10: AST Box plot distribution

Analysis on all seven post-transplant months showed deviation from Normal distributions in each month. Month 1 has extreme right skewness, and there are high value outliers (W = 0.3546, p = 0.0000) in this month, as indicated by the highly skewed graph and the large deviation in the Q-Q graph. This profound non-normality persists throughout the monitoringperiod:month2(W-statistic=0.4001,p-value=0.0000),month3(W-statistic=0.5990,p-value=0.0000), month4 (W-statistic=0.4610,p-value=0.0000),month 5 (W-statistic=0.5525,p-value=0.0000), month6(W-statistic=0.5466, p-value=0.0000), and month 7 (W-statistic= 0.5580, p-value = 0.0000) graphicx subcaption float see figure no.10,11 &12.

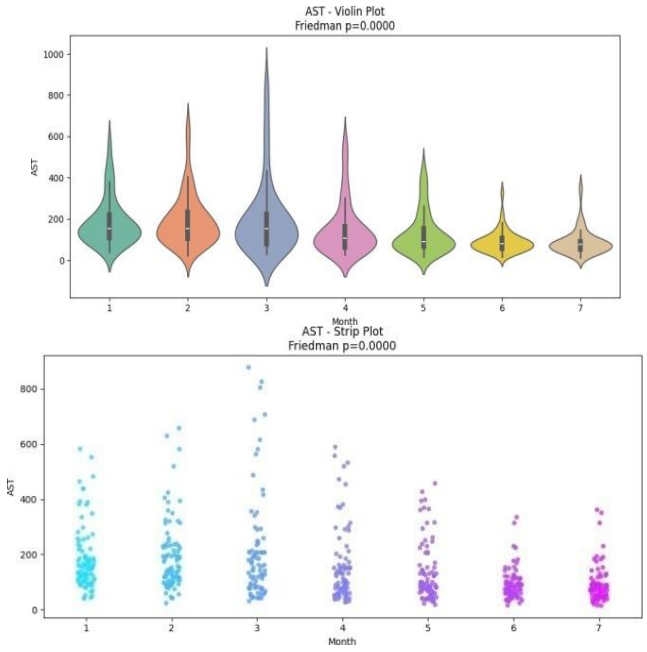


(a)After 1 month (b) After 2 month (c) After 3 month (d) After 4 month



(e) After 5 month (f) After 6 month (g) After 7 month

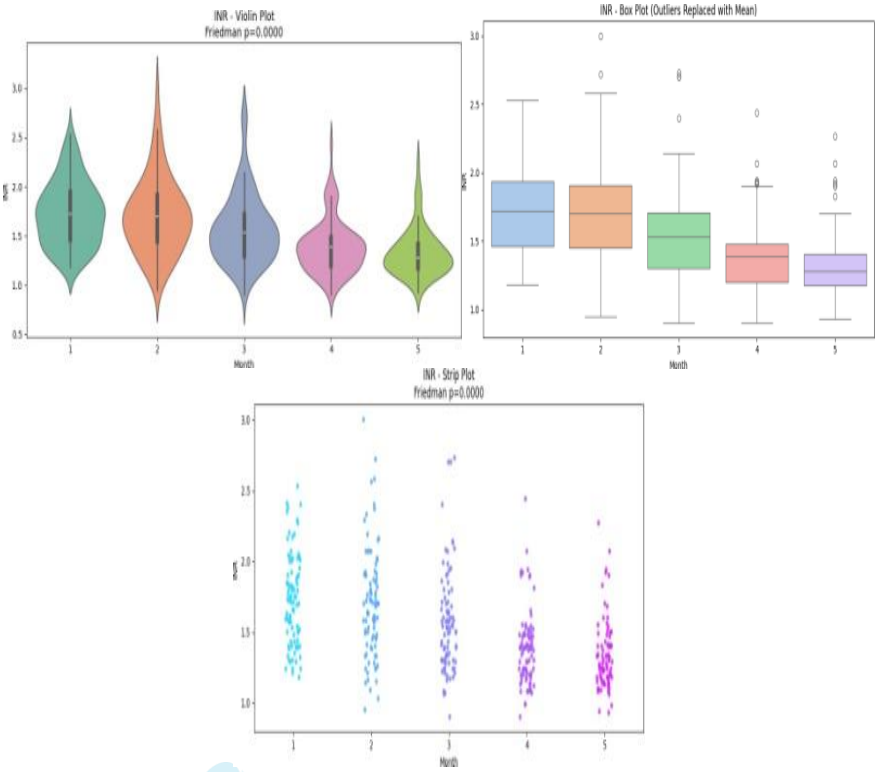
Figure 11: AST normality check from month 1to 7



(a) (b)

Figure 12: a and b is AST distribution plots

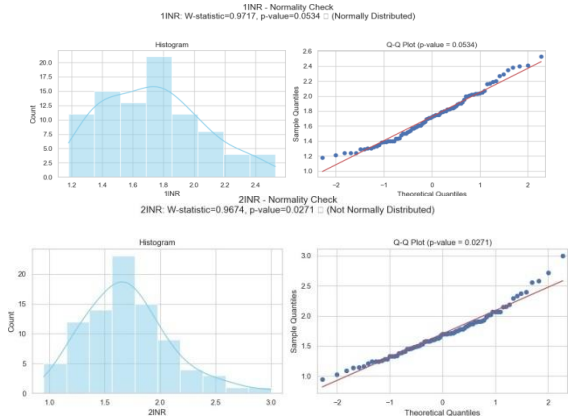
The very low W-statistics in each month of follow-up, ranging between 0.35 and 0.60, reflect highly significant deviations from normality with substantial right-skewness and multiple extreme outliers. Such patterns are also compatible with the common hepatocellular injury profile following transplantation in patients who undergo severe acute injury, while others recover more quickly. The universally serious magnitude of non-normality clearly justifies the use of robust non-parametric methods for temporal AST comparisons, such as the Friedman test, and precludes the use of parametric methods altogether. Progressive normalization shows successful graft acceptance. INR is a major indicator of hepatic synthetic function in post-transplant recipients, an elevation indicating impairment. Coagulation cascade, acute graft dysfunction, rejection, or drug-induced liver injury. Early normalization of INR (target 1.0 to 1.5) post-transplantation predicts favorable graft outcome and restoration of the liver's synthetic function. Changes of PT values over five months' post-transplantation (INR values). Examples reveal a progressive declining trajectory reflecting improving hepatic function. The strip plot shows strong clustering of INR results in the therapeutic to near-normal range (median1.5–1.8 in months 1-2, gradually dropping to 1.3–1.4 in first months reflecting patient sub- sets with more severe/delayed red graft dysfunction [9]. The violin and box plots that show this trend of decreasing values, with the highest distribution of INR in month 1 (median1.75, range 1.1-2.6) and progressive stabilization until month 5 (median1.3, range. The Friedman test confirms that there are statistical variations in INR values across the time period of interest P = 0.0000 represents a significant change in the synthetic capacity of the liver (shown in figure no. 13).



(a) (b) (c)

Figure 13: a, b and c showed Distribution plots of INR

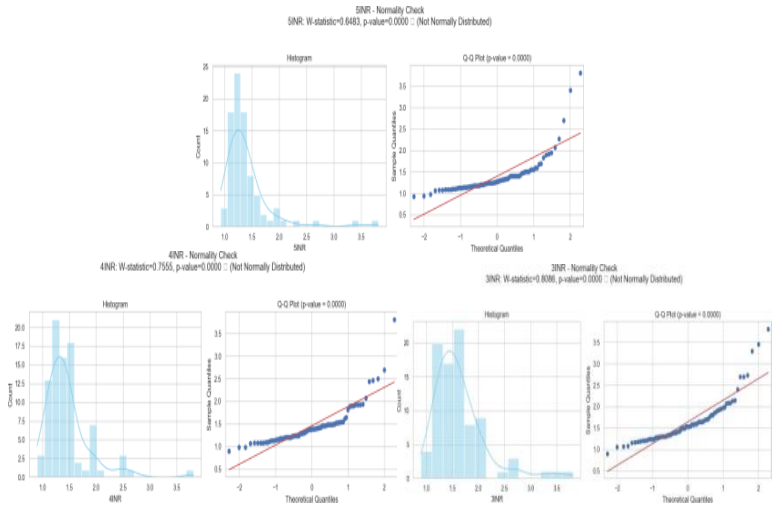
Careful analysis of the distribution of INR values for all five monitoring periods showed the existence of a remarkable disparity between the normality distribution charts. Normality tests of INR values for the first month after the operation. During the first month, the normality distribution of INR values shows near normality (normality tests: W = 0.9717, p-value = 0.0534), with a graphical representation that displays a near normal distribution with a similar Q-Q chart. This normal distribution also holds for the second month (normality tests: W = 0.9674, p-value = 0.027.



(a)After 1 month (b) after 2 months

Figure 14: Normality plots of INR after1and 2 months

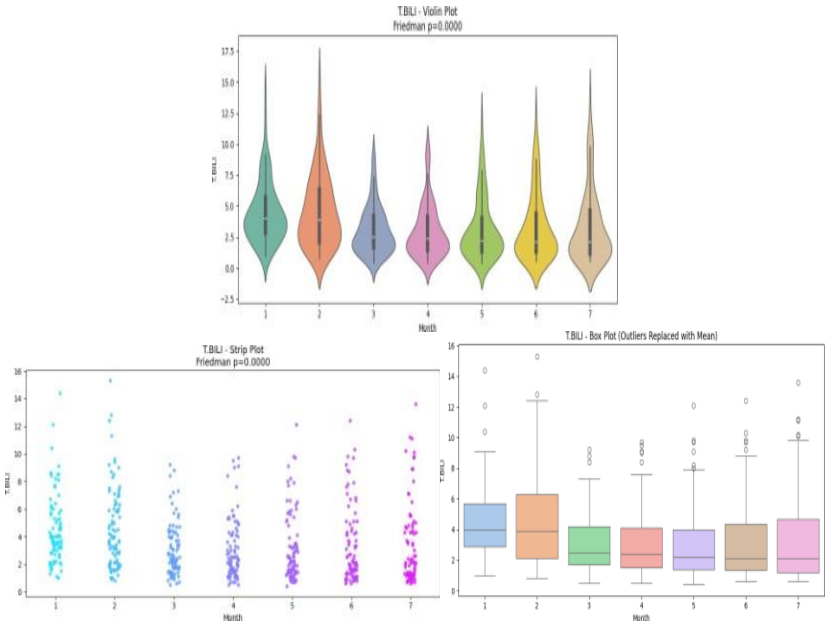
However, from month 3 onwards, INR distributions transition to significant non-normality. Month 3 exhibits pronounced non-normal distribution (W-statistic=0.8086,p-value=0.0000), characterized by left-skewness and moderate outliers visible in the Q-Q plot. This continues in Month 4 (W-Statistic = 0.7555, P-value = 0.0000) and Month 5 (W-Statistic = 0.6483, P-value = 0.0000), see figure no. 14 in which the data deviation from normality gets worse with a greater concentration of data points towards the lower end of the data.



(a)After 3 months (b) After 4 months (c) After 5 months

Figure 15: Normality checks of INR after 3,4 and 5 months

This is the natural course of changes from normality to non-normality in the expression of the biological process. Initial values of the post-transplant prothrombin time ratio (in which the majority of patients share similar levels of coagulation deficiencies) can be said to be normally distributed. As the patients recover from their post-hepatic transplant state and become stable on maintenance immune suppression therapy, the distribution of the PT-TR ratios tends towards the normal distribution but is dominated by a skewed outlier distribution reflecting the ideal range of optimal post-transplant function. The attributes of the normal distribution in this case enable the utilization of the parametric analysis in the initial stages of the biological process and the non-parametric analysis in the later stages. The increase from higher levels of the PT-TR towards normal levels in the five-month span is a strong indicator of the success of the graft engraftment and biological function of the hepatocytes post-hepatic transplant. The shift from higher levels of PT-TR (months 1-2) towards normalization or near-normal levels (months 4-5) is in line with the expected post-hepatic transplant recovery levels. the effectiveness of existing immune suppression and perioperative care regimens. In INR that persistently remains elevated after month 3, an urgent workup for acute rejection, hepatic artery thrombosis, recurrent viral hepatitis infection, or other life-threatening graft injury is required (figure no.15).



(a) (b) (c)

Figure 16: a, b and c showed Distribution plots of Total Bilirubin

According to a temporal analysis of total bilirubin concentrations over a cumulative seven-month period following transplantation, the strong tendency for decline in level and indicating restoration of normal liver excretory function. The strip plot depicts a considerable inter-patient variability in the early months post transplantation, with bilirubin levels for the first month ranging from approximately 1 to 15 mg/dL, with progressively lower levels through month seven (0.5 to 13 mg/dL) {10}. The violin and box plots highlight a dramatic finding; the highest median bilirubin for the first month (4 mg/dL), and an exponential decrease by three months (2.3 mg/dL), with gradual stabilization between months four and seven (with median levels between 2 and 3 mg/dL).{11} The Friedman test indicated significant time-dependent variation in bilirubin levels (P-value 0.0000), indicating significant time-dependent changes in the hepatic excretion capability. Thus, after performing the analyses to assess bilirubin distribution through the entire post-transplant follow-up period, it can be concluded that all seven months post-transplant demonstrated a clear departure from normality (right-skewed) due to the way in which liver was affected. Month 1 demonstrates severe non-normality (W-statistic = 0.8129, p-value = 0.0000), with markedly right-skewed histogram and substantial high-value outliers evident in the Q-Q plot. This pattern of severen on-normality persists hrough out the entire monitoring period: month 2 (W-statistic=0.9085, p-value=0.0000), month 3 (W-statistic=0.8159,p-value=0.0000),month4(W-statistic=0.7760, p-value=0.0000), month 5 (W-statistic=0.8155,p-value=0.0000), month 6 (W-statistic=0.8183,p-value=0.0000), and month 7 (W-statistic=0.7862,p-value=0.0000) (shown in figure no.16).

(a)After 1 month (b) After 2 months (c) After 3 months (d) After 4 months

(e) After 5 months (f) After 6 months (g) After 7 months

Figure 17: 7 normality check plots of Total Bilirubin after every month

Throughout all months of post-transplant follow-up, the W-statistics were consistently low, between 0.776 and 0.909, which is a strong indicator of extreme right-skewness with multiple very high outliers, which is a well-known characteristic of post-transplant bilirubin distributions. It is also true of bilirubin being an indicator of the early recovery phase in majority of the patients but delayed normalization and complications that can arise from that recovery phase in a minority of patients [18]. Therefore, given the degree and uniformity of non-normality in the bilirubin distributions for each month post-transplant, the statistical analysis should only be performed using robust, non-parametric methods like the Friedman test for all bilirubin data throughout the follow-up period. Using the parametric statistical analysis would not be appropriate due to the high degree of

uniformity and degree of non-normality see figure no.17. The clinically observed sharp reduction in median levels of bilirubin concentrations from month 1 to month 3 indicates the resolution of surgical trauma, ischemic-reperfusion injury, and initial graft rearrangement [9]. The sharp reduction observed within the first three months attests to the effective use of modern preservation and perioperative care practices. The subsequent flat phase observed within months 4 to 7, though remaining low, is likely because of the stabilization of liver function and adaptation to long-term immunosuppression. The presence of elevated bilirubin levels beyond month 2, with a value > 3.0 mg/dL, demands immediate evaluation for acute rejection, biliary, hemolytic, or vascular insufficiency. The analysis provides evidence for the complexity and heterogeneity of how biomedical parameters evolve after organ transplantation, including samples of injured hepatocytes (ALT, AST and Bilirubin) [11] The non-normal distribution is more problematic than the other factors mentioned above and is evident by the right skewed nature of the responses, with the presence of a subset having 'high' values or 'extreme values' indicating the presence of peaks, similar to what would be seen in a clinical situation where most grafts either fail to recover in a predictable manner; while only a few will exhibit significant complications. [12]. This unique characteristic of the data unequivocally supports the choice of using robust, non-parametric statistical tests for longitudinal analyses of this population, as the use of parametric statistical tests would invalidity any findings produced from conducting such analyses in this study. The temporal profiles of each measure provide a guide for monitoring. The initial spikes in both transaminase and bilirubin levels, followed by their gradual return towards normal levels, represent an expected timeline for ischemia reperfusion injury and for gauging transplant modifications [13, 14] However, the sustained presence of high outliers beyond acts as a stat [14, 15]. When patients are classified into optimal recovery or complication subsets, the initial normally for the collective dysfunction of parameters like INR can change over time.[15, 16] Biological shift from the common experience of post-operative stress to individualized healing pathways. This emphasizes the need for active surveillance techniques, where clinical knowledge and statistical models must constantly evolve with the post-transplant timeline [20].

CONCLUSION:

Understanding the trends and distributions of biomedical parameters over time is an important aspect of monitoring a patient post-transplant. The application of non-parametric analyses makes it possible to identify clinically vulnerable outliers accurately, which promotes early interventions and personalized patient care. In order to provide effective post-transplant patient care, it is imperative to comprehend the central tendencies, in addition to the distributional tendencies, of the key factors. Notably, the instability of the key biomarkers means that the median-based trends and studies will be supplemented by the need to identify and investigate
the outliers of the key factors, which include the most vulnerable patients from the clinical perspectives. Consequently, the recommended approach to patient post-transplant care will necessitate population-based protocols complemented by individual patient vigilance based on the need to identify and investigate the outliers of the key factors. The incorporation of the approach into the patient population will enable the accurate and earlier detection of the dysfunctional transplant, hence facilitating the transition from the reactive approach to patient care to predictive and personalized patient care.

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